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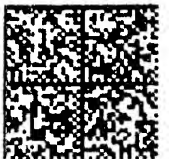
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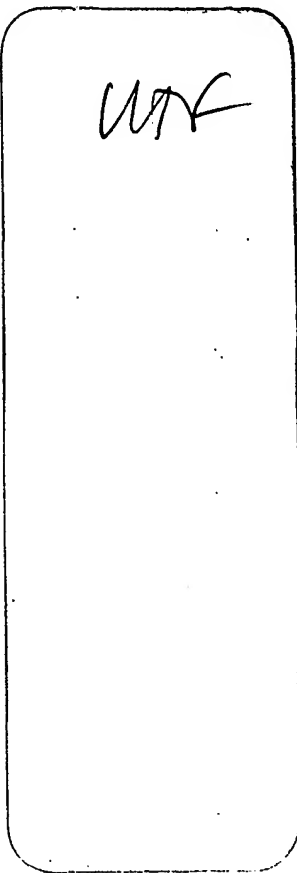
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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/719,470	11/21/2003	Qinghua Li	42P17467	2598

7590 03/13/2006

Blakely, Sokoloff, Taylor & Zafman LLP  
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EXAMINER

WILLIAMS JR, RONALD E

ART UNIT PAPER NUMBER

2121

DATE MAILED: 03/13/2006

Please find below and/or attached an Office communication concerning this application or proceeding.

<b>Office Action Summary</b>	<b>Application No.</b> 10/719,470	<b>Applicant(s)</b> LI ET AL.	
	<b>Examiner</b> Ronald E. Williams	<b>Art Unit</b> 2121	

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

**Period for Reply**

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) OR THIRTY (30) DAYS, WHICHEVER IS LONGER, FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

**Status**

- 1) ☒ Responsive to communication(s) filed on 21 November 2003.
- 2a) ☐ This action is FINAL.                      2b) ☒ This action is non-final.
- 3) ☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11; 453 O.G. 213.

**Disposition of Claims**

- 4) ☒ Claim(s) 1-19 is/are pending in the application.
- 4a) Of the above claim(s) \_\_\_\_\_ is/are withdrawn from consideration.
- 5) ☐ Claim(s) \_\_\_\_\_ is/are allowed.
- 6) ☒ Claim(s) 1-19 is/are rejected.
- 7) ☐ Claim(s) \_\_\_\_\_ is/are objected to.
- 8) ☐ Claim(s) \_\_\_\_\_ are subject to restriction and/or election requirement.

**Application Papers**

- 9) ☐ The specification is objected to by the Examiner.
- 10) ☒ The drawing(s) filed on 21 November 2003 is/are: a) ☒ accepted or b) ☐ objected to by the Examiner.  
Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).  
Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).
- 11) ☐ The oath or declaration is objected to by the Examiner. Note the attached Office Action or form PTO-152.

**Priority under 35 U.S.C. § 119**

- 12) ☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).
- a) ☐ All    b) ☐ Some \*    c) ☐ None of:
1. ☐ Certified copies of the priority documents have been received.
2. ☐ Certified copies of the priority documents have been received in Application No. \_\_\_\_\_.
3. ☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).
- \* See the attached detailed Office action for a list of the certified copies not received.

**Attachment(s)**

- |   |   |
|---|---|
| 1) <input checked="" type="checkbox"/> Notice of References Cited (PTO-892)   | 4) <input type="checkbox"/> Interview Summary (PTO-413)<br>Paper No(s)/Mail Date. _____ |
| 2) <input type="checkbox"/> Notice of Draftsperson's Patent Drawing Review (PTO-948)  | 5) <input type="checkbox"/> Notice of Informal Patent Application (PTO-152)             |
| 3) <input checked="" type="checkbox"/> Information Disclosure Statement(s) (PTO-1449 or PTO/SB/08)<br>Paper No(s)/Mail Date _____ | 6) <input type="checkbox"/> Other: _____  |

### DETAILED ACTION

1. This Office Action is responsive to application filed on November 21, 2003.
2. Claims 1-19 have been examined.

### *Claim Objections*

Claim 6 is objected to because of the following informalities: the phrase "are further to enable" is unclear, thus claim 6 appears to be incomplete. Appropriate correction is required.

### *Claim Rejections - 35 USC § 102*

The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

A person shall be entitled to a patent unless –

(e) the invention was described in (1) an application for patent, published under section 122(b), by another filed in the United States before the invention by the applicant for patent or (2) a patent granted on an application for patent by another filed in the United States before the invention by the applicant for patent, except that an international application filed under the treaty defined in section 351(a) shall have the effects for purposes of this subsection of an application filed in the United States only if the international application designated the United States and was published under Article 21(2) of such treaty in the English language.

Claims 1-19 are rejected under 35 U.S.C. 102(e) as being anticipated by Boros et al. (USPN: 6,615,024).

### Regarding Claim 1:

An apparatus, comprising:

A first electronic device (**see Figure 1, element 101-Base Station**) adapted to perform

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a training phase (**see col. 13, lines 4-10**) with multiple second electronic devices (**Figure 1, element 105-Antenna array**) to calculate parameters to enable substantially simultaneous spatial division multiple access transmissions to multiple ones of the multiple second electronic devices; (**see col. 1, lines 54-62**)  
a data phase by using the parameters to perform the spatial division access transmissions; (**see col. 2, lines 26-29**)

**Regarding Claim 3:**

The apparatus of claim 1, wherein the first electronic device is further adapted to perform the data phase by:  
transmitting substantially simultaneous data polls to the multiple ones of the multiple second electronic devices through multiple antennas; (**see Figure 10**) and  
receiving substantially simultaneous data responses from the multiple ones of the multiple second electronic devices through multiple antennas. (**see Figure 9**)

**Regarding Claim 4:**

The apparatus of claim 1, wherein the first electronic device is further adapted to perform the training phase by:  
transmitting training polls to the multiple second electronic devices; (**see Figure 10**)  
receiving training responses from the multiple second electronic devices through multiple antennas; (**see Figure 9**)

Art Unit: 2121

processing the training responses received through the multiple antennas; **(see col. 13, lines 34-38)** and calculating the parameters based on the processed training responses. **(see col. 13, lines 34-38)**

**Regarding Claim 5:**

The apparatus of claim 1, wherein the parameters comprise beam forming parameters. **(see col 12, lines 63 to col 13 line 3 and col 13, lines 30-34)**

**Regarding Claim 6:**

The apparatus of claim 1, wherein the parameters are further to enable substantially simultaneous spatial division multiple access receptions from the multiple ones of the multiple second electronic devices. **(see col. 1, lines 54-62)**

**Regarding Claim 7:**

The apparatus of claim 1, wherein the first electronic device further comprises at least four antennas to communicate with the multiple second electronic devices during the training phase and the data phase. **(see col. 13, lines 50-52)**

**Regarding Claim 8:**

The apparatus of claim 7, wherein the first electronic device further comprises a computing platform coupled to the at least four antennas. **(see Figure 1, element 117-**

**Transmit Weight Generator and col. 13, lines 37-38)**

**Regarding Claim 9:**

The apparatus of claim 8, wherein the first electronic device further comprises at least four modulator/demodulators with at least one modulator/demodulator coupled between each of the at least four antennas and the computing platform. **(see col. 3, lines 37-45. “and analog-to-digital converter (“ADC”) if processing is digital.” The analog-to-digital converter disclosed by Boros et al. is the modulator/demodulator claimed by the applicant.)**

**Regarding Claim 10:**

The apparatus of claim 9, wherein the first electronic device further comprises multiple analog-to-digital converters and multiple digital-to-analog converters with at least one analog-to-digital converter and at least one digital-to-analog converter coupled between each modulator/demodulator and the computing platform. **(see col. 3, lines 37-45)**

**Regarding Claim 11:**

A method, comprising:

transmitting a training poll to a first mobile device; **(see Figure 10)**

receiving a training response from the first mobile device; **(see Figure 9)**

transmitting a training poll to a second mobile device; **(see Figure 10)**

receiving a training response from the second mobile device; **(see Figure 9)**

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calculating parameters based on the received training response from the first mobile device and the received training response from the second mobile device; **(see col. 13, lines 34-38)** and using the parameters to enable spatial division multiple access transmissions to the first and second mobile devices. **(see col. 2, lines 26-29)**

**Regarding Claim 12:**

The method of claim 11, wherein said using comprises:

transmitting a first data poll to the first mobile device and a second data poll to the second mobile device substantially simultaneously using spatial division multiple access techniques; **(see Figure 10)** and

receiving a response to the first data poll from the first mobile device and a response to the second data poll from the second mobile device substantially simultaneously. **(see Figure 9)**

**Regarding Claim 14:**

The method of claim 13, wherein said calculating the parameters comprises calculating beam forming parameters. **(see col. 12, lines 63 to col. 13, line 3 and col. 13, lines 30-34)**

**Regarding Claim 15:**

The method of claim 13, wherein the parameters are further used to enable spatial division multiple access receptions from the first and second mobile devices. **(see col.**



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**1, lines 54-62)**

**Regarding Claim 16:**

A machine-readable medium that provides instructions, which when executed by a processing platform, cause said processing platform to perform operations comprising:

transmitting a training poll to a first device; **(see Figure 10)**

receiving a training response from the first device; **(see Figure 9)**

transmitting a training poll to a second device; **(see Figure 10)**

receiving a training response from the second device; **(see Figure 9)**

calculating parameters based on the received training response from the first device and the received training response from the second device; **(see col. 13, lines 34-38)**

and using the parameters to enable substantially simultaneous transmissions to the first and second devices using spatial division multiple access techniques. **(see col. 2, lines 26-29)**

**Regarding Claim 17:**

The medium of claim 16, wherein said operations further comprise:

using the parameters to enable transmitting a data poll to the first device and a data poll to the second device substantially simultaneously using the spatial division multiple access techniques; **(see Figure 10 and col. 2, lines 26-29)**

and using the parameters to enable receiving a data response from the first device and a data response from the second device substantially simultaneously using the spatial

division multiple access techniques. (see Figure 9 and col. 2, lines 26-29)

**Regarding Claim 19:**

The medium of claim 16, further comprising using the parameters to enable substantially simultaneous receptions from the first and second devices using the spatial division multiple access techniques. (see col. 1, lines 54-62) .

***Claim Rejections - 35 USC § 103***

The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

(a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negated by the manner in which the invention was made.

Claims 2, 13, and 18 are rejected under 35 U.S.C. 103(a) as being unpatentable over Boros et al. in view of Ren Tianmin (IEEE: Efficient Media Access Protocols for Wireless LANs with Smart Antennas, 2003)

Boros fails to disclose an apparatus wherein the first electronic device is further adapted to perform an acknowledgement phase by using the parameters to perform substantially simultaneous spatial division multiple access transmissions of acknowledgements to the multiple ones of the second electronic devices subsequent to the data phase.

Tianmin discloses a wireless network that utilizes smart antennas and the SDMA protocol. In addition Tianmin teaches an apparatus wherein the first electronic device

is further adapted to perform an acknowledgement phase by using the parameters to perform substantially simultaneous spatial division multiple access transmissions of acknowledgements to the multiple ones of the second electronic devices subsequent to the data phase. (see pg 1288, B. Contention-based polling with directed transmissions, col. 1, lines 9-18 to col. 2, lines 1-21)

It would be obvious to one of ordinary skill in the arts at the time of invention to modify the invention taught by Boros et al. to include the acknowledgement phase taught by Tianmin et al. providing better communication between base stations and users.

### ***Conclusion***

Any inquiry concerning this communication or earlier communications from the examiner should be directed to Ronald E. Williams whose telephone number is 571 272 2590. The examiner can normally be reached on MWF 7-4:30.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Anthony Knight can be reached on 571 272 3687. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see <http://pair-direct.uspto.gov>. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free).



Anthony Knight  
Supervising Patent Examiner  
Tech Center 2100

RW

Substitute for form 1449A/PTO

# INFORMATION DISCLOSURE STATEMENT BY APPLICANT

**(use as many sheets as necessary)**

Sheet 1 of 1

**Complete if Known**

Application Number	10/719,470
Filing Date	November 21, 2003
First Named Inventor	Qinghua Li
Art Unit	1614
Examiner Name	Not Yet Assigned
Attorney Docket Number	42P17467

## U.S. PATENT DOCUMENTS

[illegible]

## FOREIGN PATENT DOCUMENTS

[illegible]

Examiner Signature	<i>Dana E. Williams</i>	Date Considered	12/30/05
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\*Examiner: Initial if reference considered, whether or not citation is in conformance with MPEP 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication.

\*Applicant's unique citation designation number (optional). See Kinds Codes of USPTO Patent Documents at [www.uspto.gov](http://www.uspto.gov) or MPEP 901.04. Enter Office that issued the document, by the two-letter code (WIPO Standard ST.3). For Japanese patent documents, the indication of the year of reign of the Emperor must precede the serial number of the patent document. Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST. 16 if possible. Applicant is to place a check mark here if English language translation is attached.

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Substitute for form 1449A/PTO

# INFORMATION DISCLOSURE STATEMENT BY APPLICANT

*(use as many sheets as necessary)*

Sheet	1	of	2
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**Complete if Known**

Application Number	10/719,470
Filing Date	November 21, 2003
First Named Inventor	Qinghua Li
Art Unit	1614
Examiner Name	Not Yet Assigned
Attorney Docket Number	42P17467

## U.S. PATENT DOCUMENTS

[illegible]

## FOREIGN PATENT DOCUMENTS

[illegible]

**Examiner  
Signature**

Date \_\_\_\_\_

**Considered**

12/30/05

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\*Applicant's unique citation designation number (optional). See Kinds Codes of USPTO Patent Documents at [www.uspto.gov](http://www.uspto.gov) or MPEP 901.04. Enter Office that issued the document, by the two-letter code (WIPO Standard ST.3). For Japanese patent documents, the indication of the year of reign of the Emperor must precede the serial number of the patent document. Kind of document by the appropriate symbols as indicated on the document under WIPO Standard ST. 16 if possible. Applicant is to place a check mark here if English language Translation is attached.

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Substitute for form 1449A/PTO <b>INFORMATION DISCLOSURE STATEMENT BY APPLICANT</b>			<b>Complete if Known</b>		
			Application Number	10/719,470	
			Filing Date	November 21, 2003	
			First Named Inventor	Qinghua Li	
			Art Unit	1614	
			Examiner Name	Not Yet Assigned	
Sheet	2	of	2	Attorney Docket Number	42P17467

NON PATENT LITERATURE DOCUMENTS				
Examiner Initials*	Cite No.†	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.		
RW	4	YOUNG-BAE et al: "Medium Access Control Protocols Using Directional Antennas in Ad Hoc Networks: Infocom 2000. IEEE Tel Aviv, Israel 26-30 March 2000. pages 13-21 XP010376001		
RW	5	SAKR et al: "Carrier-Sense Protocols for Packet-Switched Smart Antenna Basestations" IEEE 28 October 1997, pages 45-52, XP10258685		
RW	6	KRISHNAMURTHY et al: "Polling-Based Media Access Protocols for Use with Smart Adaptive Array Antennas"		
RW	7	REN: "Efficient Media Access Protocols for Wireless LANs with Smart Antennas" 2003 IEEE 16-20 March, Piscataway NJ, vol. 2 pages 1286-1290, XP010639952		
RW	8	PCT Search report dated 3-18-05		

Examiner Signature	<i>Donald E. Smith</i>	Date Considered	12/30/05
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†Applicant's unique citation designation number. Applicant is to place a check mark here if English language Translation is attached.

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<b>Notice of References Cited</b>	Application/Control No. 10/719,470	Applicant(s)/Patent Under Reexamination LI ET AL.	
	Examiner Ronald E. Williams	Art Unit 2121	Page 1 of 1

**U.S. PATENT DOCUMENTS**

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	Classification
*	A	US-2003/0032390	02-2003	Geile et al.	455/3.05
*	B	US-6,615,024	09-2003	Boros et al.	455/67.14
*	C	US-6,185,440	02-2001	Barratt et al.	455/562.1
*	D	US-6,037,898	03-2000	Parish et al.	342/174
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	G	US-			
	H	US-			
	I	US-			
	J	US-			
	K	US-			
	L	US-			
	M	US-			

**FOREIGN PATENT DOCUMENTS**

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
*	N	EP 1263168 A2	12-2002	European Patent	KASAMI et al.	H04L 12/28
	O					
	P					
	Q					
	R					
	S					
	T					

**NON-PATENT DOCUMENTS**

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
*	U	Okamoto G & Xu G. (1997) The Smart Wireless LAN System: Physical Layer Design and Results. IEEE
*	V	Warneke B. ; Atwood B. ; Pister S.J. K. (2001) Smart Dust Mote Forerunner. IEEE
	W	Tianmin R. ; Koutsopoulos I. ; Tassiulas L. ; (2003) Efficient Media Access Protocols for Wireless LANs with Smart Antennas. IEEE
	X	

\*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)  
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.



# Efficient Media Access Protocols for Wireless LANs with Smart Antennas

Tianmin Ren, Iordanis Koutsopoulos and Leandros Tassiulas

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**Abstract**— The use of smart antennas in extending coverage range and capacity of wireless networks dictates the employment of novel media access control protocols, with which the base station (BS) or access point (AP) provides access to users by learning their locations. We consider the class of protocols that employ beamforming and use contention-based or contention-free polling methods to locate users residing in or out of coverage range of the AP. Such protocols allow rapid media access and can be embedded in existing MAC protocols.

## I. INTRODUCTION

The increasing need for providing fast wireless access and high-speed wireless links to users has become the driving force for active research in the telecommunications area. The advent of services such as home networking, video conferencing, wireless internet access and multimedia transmission is only the first sign of the projected demand for rapid and reliable access to information sources of any kind. The requirement for ubiquitous coverage in personal, local and wide area networks and the demand for mobility necessitate the deployment of efficient protocols for wireless access in indoor and outdoor environments. In such systems, the final interface between the mobile user and the network is wireless through APs or base BSs that are wired to the backbone network.

A major challenge in the design of wireless systems is quality of service (QoS) provisioning to users. Different notions of QoS are available in different phases of the link establishment procedure and in different communication layers. When a link needs to be established between an AP and a user, QoS is expressed in terms of link setup time delay and can be ensured with efficient media access control (MAC) protocols. After link establishment, QoS at the physical layer is given in terms of an acceptable signal-to-interference and noise ratio (SINR) or bit error rate (BER) at the receiver of a user or in terms of minimum throughput guarantees at higher layers. QoS is then provided with appropriate resource allocation techniques. Space division multiple access (SDMA) with smart antennas at the AP constitutes perhaps the most promising means for ensuring these notions of QoS and increasing system capacity [1]. SDMA

enables intra-cell channel reuse by several spatially separable users by pointing a beam towards the direction of a user and nulling out other users. However, the employment of antenna arrays at the physical layer affects resource allocation methods and MAC protocols of higher layers. With respect to the impact of SDMA on resource allocation, some heuristics for time slot assignment to users in a SDMA/TDMA system are proposed in [2] and [3].

In order to exploit the benefits of SDMA in MAC protocols, the BS needs to know the location of each user, which is captured by its spatial signature. In reception mode, the BS obtains information about spatial signatures of users by making use of the preamble of received packets. Each preamble is used by the BS to train the array to compute beamforming weights that effectively steer the beam towards the intended user. In [4], the authors describe a slotted ALOHA network with a single-beam adaptive array at the BS. By exploiting a pseudo-random sequence in the packet preamble, the BS computes a beam and locks it onto the first received packet in a slot, while nulling subsequently received packets. A similar system with multi-beam capabilities is presented in [5]. The BS again uses packet preambles to form a beam for each received packet from a different user, so that several users are captured. Up-link access to a base station with an antenna array with the help of a modified carrier sense multiple access (CSMA) protocol is addressed in [6]. In transmission mode, the BS can request information about the spatial signature of a user by broadcasting a polling message intended for that user in the down-link [7]. Upon reception of the poll, the user transmits a given sequence of symbols. The BS measures the received signal and uses it to compute the spatial signature and gradually steer a beam towards the direction of the user.

The common characteristic of these approaches is that they are all designed for users that reside within the omnidirectional transmission range of the AP or BS. When required, the AP broadcasts polling requests to users and receives response packets from users within broadcast range by having its antenna in omnidirectional mode. It then uses packet preambles to steer beams to appropriate directions. In this setting, the basic feature of SDMA to extend coverage

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The rest of the paper is organized as follows. In section II we provide the model and main assumptions and in section III we present our protocols and analyze their performance. Numerical results are presented in section IV. Finally, section V concludes our study.

We consider the down-link of a single AP and focus on down-link access to  $N$  users. The AP is equipped with a uniform linear array of  $M$  antennas. The broadcast range of the AP is specified by a maximum transmission power level when the array operates in simple omni-directional mode. Users can reside in or out of broadcast range of the AP. Due to mobility, they can also move in or out of range at different time instants. A snapshot of the system is considered, where users remain either within or out of range. The AP has  $C$  available transceivers and each transceiver is perceived as a distinct communication unit that is capable of forming one beam. In this work, we consider the class of protocols with  $C = 1$ , so that one beam can be formed at each time instant. A beam is described by an  $M \times 1$  beamforming vector  $\mathbf{w} = (w_1, \dots, w_M)^T$ , where  $w_i$ 's are complex numbers and  $\mathbf{w}^H \mathbf{w} = 1$ , so that the beam has fixed power. Alternatively, a beam is specified by its beam width  $\delta$  and its angular position  $\phi$ . We assume that a beamforming vector uniquely specifies the pair  $(\delta, \phi)$  and vice versa. The space can be covered by  $B$  beams of beam width  $\delta = 360/B$  degrees and each user is covered by at least one beam. Depending on parameter  $B$ , the patterns of two successive beams can partially overlap.

$\delta$  : beam width  
 $\phi$  : angular position

Fig. 1. Beam width and angular position of a beam.

The AP can obtain information about the location of a user by using the following two methods. According to the first one, it first sends a polling message that contains the address of the intended user. Upon receiving the poll, the user responds by sending a known sequence of bits in the up-link. The AP uses these bits to train the array so as to steer the beam towards the direction indicated by the spatial signature of the user. This polling/response method is used to acquire the spatial signature of each user. We refer to this method as contention-free polling, since it does not involve any kind of user contention. Alternatively, the AP can acquire information about user locations by sending a beacon message that is not intended for a specific user. If the message is received by more than one users, their simultaneous responses will collide at the AP. The AP then initiates a contention resolution procedure to resolve users and obtain their spatial signatures. We refer to this method as contention-based polling. The AP can send polling messages with omni-directional or directional transmission. After the spatial signature acquisition process is completed, data can be transmitted to users.

### A. Problem Statement

When the AP needs to obtain information about the spatial signature of a user residing within its broadcast range, it can poll the user by using broadcast or directed transmission with contention-free or contention-based polling. Contention-free broadcast polling is the method that results in the smallest time delay in locating all users.

However, when the user is out of broadcast range, it cannot be reached by a simple broadcast transmission. The AP needs to concentrate all transmission power into a narrower directed beam so that it reaches the user. An arising issue concerns the polling protocol that should be devised, such that the AP acquires the spatial signatures of users out of broadcast range in a fast and reliable manner. Towards this end, the AP can use beamforming to send polling messages with long range directed transmissions. The AP sequentially

steers the beam towards different directions, so that the entire space is covered. In this case we have maximum range polling through successive directed transmissions that scan the space. The objective of the protocol is to locate all users as fast as possible.

The AP can select between contention-free and contention-based polling with directed transmissions in order to locate users out of broadcast range. In contention-free polling, the space is successively scanned by a beam until the user is located and the procedure is repeated for all users. In contention-based polling, the space is successively scanned by a beam in a different direction and the contention among users in a beam is resolved before proceeding to the next beam. The absence of contention in contention-free polling is the advantage of this method over contention-based polling. However, the time consumed in scanning the space to locate each user separately may be larger than the corresponding time with contention-based polling. A significant issue that arises in contention-based polling is that of the width of the beam that scans the space. If a large beam width is used, fewer beams are needed to scan the space and the required time to scan the space with successive directed transmissions is smaller. However, with a large beam width, the number of users that receive the message is larger on average and hence the contention resolution for users in a beam lasts longer. From that point of view, a large beam width does not contribute to reduction of time delay to locate all users. A similar tradeoff holds for small beam widths as well.

We address the problem of extending the coverage range of the AP by providing media access to users that are located out of its broadcast range. We describe contention-based and contention-free protocols and analyze their performance with respect to several involved parameters.

#### B. Contention-based polling with directed transmissions

When contention-based polling is employed, the AP forms successive directed beams and scans all the space. The AP attempts to locate all users within a beam before proceeding to the next beam. For now assume that the AP employs directed transmission for all users, regardless if they are in or out of broadcast range.

Time is divided in slotted intervals that are referred to as contention resolution intervals (CRI). Each CRI consists of  $L$  contention slots. At the beginning of a CRI, the AP sends a polling message by using directed transmission. The polling message does not contain the address of any user. Each user that is illuminated by that beam receives the message and responds by sending back a polling acknowledgement (P\_ACK) message that contains a preamble and the user address. If only one user sends a P\_ACK, the message is received correctly by the AP and the spatial signature of the user is obtained with the help of the preamble. In that case, the AP informs the user that his spatial signature is known,

by sending him an ACK message with his address. However, if there are multiple users in the beam, their P\_ACK messages collide at the AP. The AP then does not issue an ACK to users in the beam and users are informed about the collision and the upcoming contention. A simple method is used for resolving the collisions: each user with a collided P\_ACK retransmits with probability  $p$  in each of the subsequent  $L$  slots in the CRI. If one user happens to transmit alone in one slot, the message of this user is resolved. Then, the AP informs the user that his P\_ACK is obtained (and hence his spatial signature is known) by sending an ACK message to the user, so that he defers from transmission in the next slots. If no user sends a P\_ACK in a slot following the polling message, the AP assumes that no user is located in the beam or that all users have been resolved in previous slots. It then proceeds by forming the next beam. If the CRI expires and the AP does not have any indication that all users have been resolved, it initiates the next CRI by sending a polling message again. The procedure is repeated for the remaining unresolved users, until the AP has an indication that all users in the beam are resolved.

Our assumption for using a fixed retransmission probability  $p$  in each slot is justified as follows. Assume that there exist  $n$  unresolved users in a beam. The probability that one user transmits in a slot and therefore succeeds in transmission is  $p_s(n) = np(1-p)^{n-1}$ . This probability is maximized for  $p^* = 1/n$ , which depends on the number of unresolved users. Ideally, the AP could instruct users to retransmit with probability  $p^*$ , so as to improve the chances of a successful transmission. The problem is that the AP is not aware of the number of users in a beam and therefore it does not know the number of unresolved users at each step of the procedure. Thus, we resort to a fixed value  $p$ .

Let us now compute the expected time  $d(n)$  to obtain the spatial signature of  $n$  users in a beam. Let  $X_p$ ,  $X_{p,a}$  and  $X_a$  denote the time length of poll, P\_ACK and ACK messages respectively. Define  $p_{i,n,L}$  as the probability that  $i$  out of  $n$  users have already been resolved successfully in  $L$  contention resolution slots. Then,  $p_{1,n,1} = p_s(n)$  and  $p_{i,n,L} = 0$  if  $i > n$  or  $i > L$ . For all other cases,  $p_{i,n,L}$  can be computed with the recursive equation,

$$p_{i,n,L} = p_s(n)p_{i-1,n-1,L-1} + (1-p_s(n))p_{i,n,L-1}. \quad (1)$$

For the time delay  $d(n)$ , we have  $d(0) = X_p$  and  $d(1) = X_p + X_{p,a} + X_a$ , while for  $n \geq 2$  it is

$$d(n) = \sum_{k=0}^n p_{k,n,L} [X_p + X_{p,a} + LX_{p,a} + kX_a + d(n-k)]. \quad (2)$$

In the beginning of a CRI, a polling message is sent and the polling response from users (collided or not) is received. If  $k$  out of  $n$  users are resolved in  $L$  contention slots, this means that the AP has received P\_ACKs from users that retransmit in the intervals following each one of the  $L$  contention slots

and it has sent  $k$  ACKs to resolved users. The term  $d(n - k)$  accounts for the fact that  $n - k$  users still need to be resolved.

We now compute the expected time  $D(N, B)$  to resolve all  $N$  users and obtain their spatial signatures when the space is covered by  $B$  successive directed transmissions. Let  $q_{i,N,B}$  be the probability that  $i$  out of  $N$  users reside in a beam. Assuming that users can reside in each of the  $B$  beams with probability  $1/B$ ,  $q_{i,N,B}$  is given by

$$q_{i,N,B} = \binom{N}{i} \left(\frac{1}{B}\right)^i \left(1 - \frac{1}{B}\right)^{N-i} \quad (3)$$

and the delay  $D(N, B)$  can be computed recursively as,

$$D(N, B) = \sum_{i=0}^N q_{i,N,B} [d(i) + D(N - i, B - 1)] \quad (4)$$

where the first term in the brackets denotes the delay to resolve  $i$  users in a beam and the second term indicates that  $N - i$  users need to be resolved in the remaining  $B - 1$  beams.

### C. Contention-free polling with directed transmissions

When contention-free polling is used, the AP again forms successive directed beams to poll users. However, polling messages now include the address of a user and are intended for that user. The AP attempts to locate one user by sequentially scanning the space with successive directed transmissions. The AP starts by sending a polling message for a user in a beam. If the user does not reside in the beam, the AP does not receive any reply and proceeds with the formation of the next beam to locate the user. If the user is found to reside in a beam, it responds by sending a P\_ACK message. Upon receiving P\_ACK, the AP finds its spatial signature and sends an ACK message to the user to inform him that his location is found. It then starts scanning the space for another user. The order in which users are sought is arbitrary.

The advantage of this scheme is the absence of contention among users in a beam, since only one user responds to the polling message. However the time delay to locate all  $N$  users is highly dependent on the distribution of users in the area around the AP. Clearly, the minimum time delay is achieved when all users reside in the first beam that is formed while scanning the space, while the maximum time delay occurs if all users reside in the beam that is formed last. The expected delay  $D'(N, B)$  to obtain the spatial signatures of  $N$  users when covering the space with  $B$  beams is,

$$D'(N, B) = N \left( \frac{B+1}{2} X_p + X_{p,a} + X_a \right) \quad (5)$$

Indeed, for each user the AP issues  $(B + 1)/2$  polls on average, receives one polling response when the user is located and sends one ACK to the user.

## IV. NUMERICAL RESULTS

### A. Simulation Setup

We consider a scenario where  $N$  users are uniformly distributed in an area around an AP, so that they can reside either in or out of the AP broadcast range. The AP needs the spatial signature of all users and can poll users with omni-directional or directional transmission. At each time one beam can be formed towards a certain direction and the area around the AP is covered by  $B$  beams. For users within broadcast range, the AP may select to poll users by broadcasting or directional beamforming and can use contention-based or contention-free transmission. For users out of broadcast range, the AP can use only beamforming to poll users. The time lengths of the polling, P\_ACK and ACK messages were chosen to satisfy the ratios  $X_p : X_{p,a} : X_a = 1 : 2 : 1$ . This selection is justified by the fact that all messages have an address field and the P\_ACK message also has a preamble for spatial signature acquisition. CRIs consist of  $L$  slots. The intervals between transmission of polling messages, reception of polling responses and transmission of ACKs were not considered in the analysis.

### B. Comparative Results

The performance measure is time delay until spatial signatures of users are acquired. We evaluate the performance of four schemes:

- Broadcasting/Beamforming (Broad/Beam) scheme. The AP uses contention-free broadcast polling for users in broadcast range and uses polling with beamforming for users out of range. The latter can be contention-based or contention-free.
- Beamforming/Beamforming (Beam/Beam) scheme. The AP uses polling with beamforming for all users, regardless if they reside in or out of broadcast range. The polling can again be contention-based or contention-free.

In figures 2 and 3, we illustrate the performance of the aforementioned schemes for  $N = 20$  users for  $B = 5$  and  $B = 15$  beams. The time delay is plotted as a function of the number of users  $N_{out}$  that reside out of broadcast range. A first observation is that the performance of the Beam/Beam contention-based and contention-free schemes is independent of  $N_{out}$ , since these schemes treat users residing in and out of range the same. The time delay for contention-free schemes increases linearly with the number of users, as can be seen from (5). For  $B = 5$ , the Broad/Beam and Beam/Beam contention-free schemes perform better than corresponding contention-based ones. This is because the small value of  $B$  results in fast enough contention-free polling and because beams are wide enough, so that time latency due to user contention is large. When  $N_{out} < 14$ , Broad/Beam contention-free scheme yields the best performance. Beam/Beam contention-free scheme is more preferable when  $N_{out} > 15$ , because in the Broad/Beam scheme

time is wasted in issuing broadcast polling messages that are not received by users residing out of range. When  $B = 15$ , the behavior is reversed, namely contention-based schemes incur smaller delay than contention-free ones. The large value of  $B$  makes contention-free polling time-consuming, while at the same time user contention within each beam becomes low, since beams are narrow. Broad/Beam contention-based polling yields the smallest delay when  $N_{out} < 17$ , while Beam/Beam with contention achieves the best performance in all other cases. From other conducted experiments for  $B > 10$ , it seems that Broad/Beam with contention should be selected when users out of range represent less than 75 – 80% of the total number of users. Similar conclusions can be drawn from figure 4, where the ratio of number of users out of and within range,  $N_{out}/N_{in}$  was fixed to 1/2.

## V. DISCUSSION

We addressed the problem of extending the coverage range of the AP by providing media access to users out of broadcast range with beamforming. Our primary goal was to design protocols that can be easily integrated with existing polling protocols that use omni-directional transmission. We considered the class of media access protocols with contention-based and contention-free polling and evaluated their performance in terms of required time so that the AP becomes aware of user locations and grants access to the system.

There exist several directions for future study. An interesting situation arises if the AP is equipped with several transceivers. Then, multiple beams can be formed to scan the space simultaneously towards different directions, so that the time required to locate users is reduced. A synergy between beams could further improve protocol performance. Furthermore, the possibility of adapting beam width in different stages of the algorithm, depending on the outcome of the contention resolution process is another issue that deserves further investigation.

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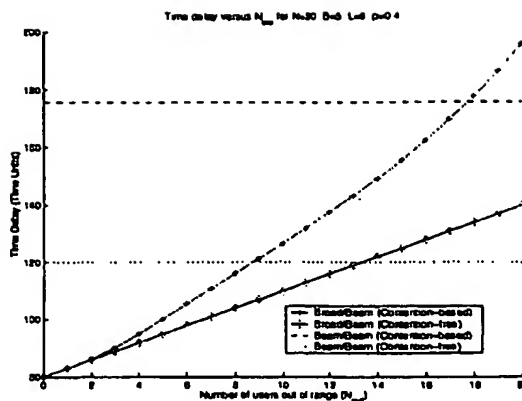


Fig. 2. Time delay as a function of number of users out of broadcast range for  $N = 20$  users when  $B = 5$  beams scan the space.

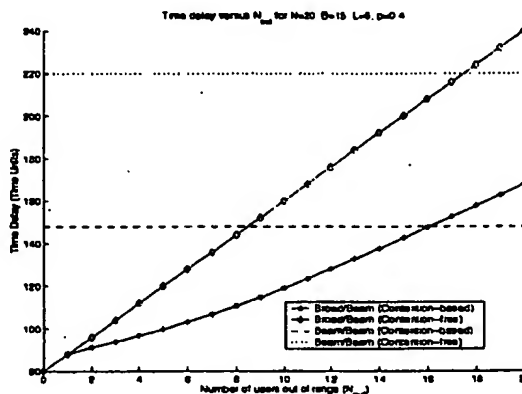


Fig. 3. Time delay as a function of number of users out of broadcast range for  $N = 20$  users when  $B = 15$  beams scan the space.

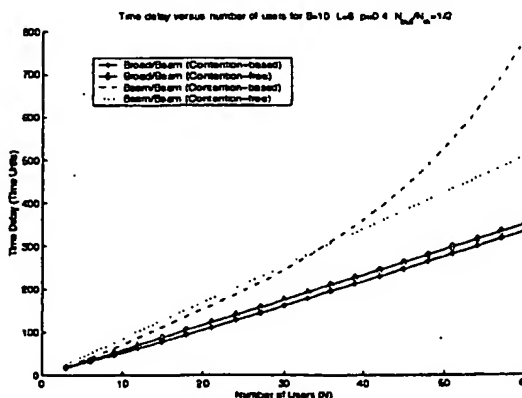


Fig. 4. Time delay as a function of number of users, when ratio  $N_{out}/N_{in} = 1/2$  and  $B = 10$  beams scan the space.